

A Tale of Two Forcings: Present-day Coupled Antarctic Ice-sheet/Southern Ocean Dynamics using the POPSICLES Model

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Joint work with:

- Xylar Asay-Davis (Potsdam-PIK)
- Stephen Cornford (Bristol)
- Stephen Price (LANL)
- Doug Ranken (LANL)
- Mark Adams (LBNL)
- Esmond Ng (LBNL)
- William Collins (LBNL)



Coupled Ice and Ocean Models:

- ❑ Ocean Circulation Model: POP2x
 - ❑ Ice Sheet: BISICLES (CISM-BISICLES)
 - ❑ POP + BISICLES = POPSICLES



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Coupling: Synchronous-offline

- Monthly coupling time step ~ based on experimentation
- BISICLES → POP2x: (instantaneous values)
 - ice draft, basal temperatures, grounding line location
- POP2x → BISICLES: (time-averaged values)
 - (lagged) sub-shelf melt rates
- Coupling offline using standard CISIM and POP netCDF I / O
- POP bathymetry and ice draft recomputed:
 - smoothing bathymetry and ice draft, thickening ocean column, ensuring connectivity
 - T and S in new cells extrapolated iteratively from neighbors
 - barotropic velocity held fixed; baroclinic velocity modified where ocean column thickens/thins



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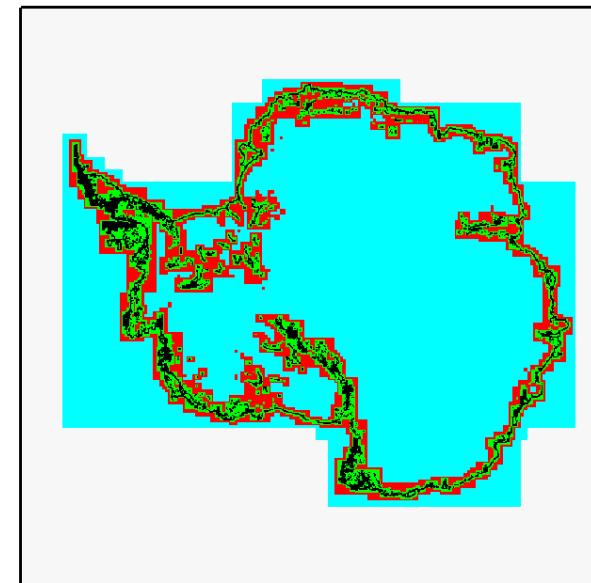
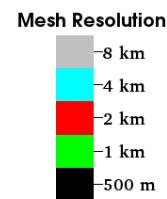
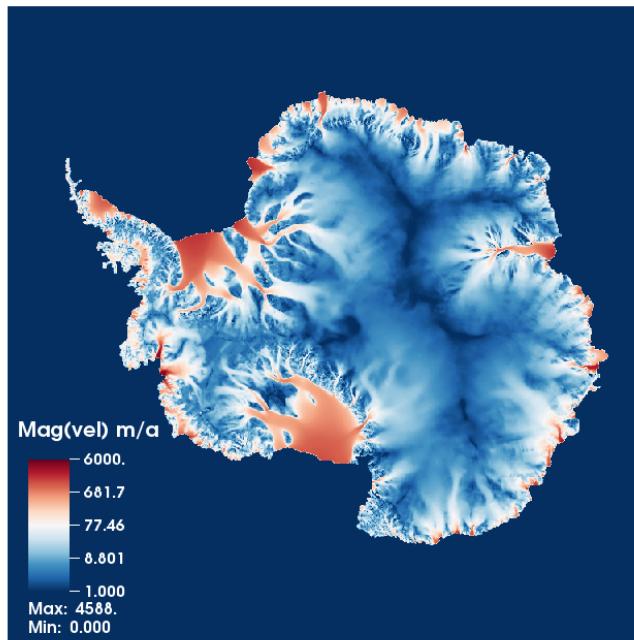
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Antarctic-Southern Ocean Coupled Simulations

BISICLES setup:

- Full-continent Bedmap2 (2013) geometry
- Initialize to match Rignot (2011) velocities
- Temperature field from Pattyn (2010)
- 500m finest resolution (adaptive mesh refinement)
- Initialize SMB to “steady state” using POP standalone melt rate



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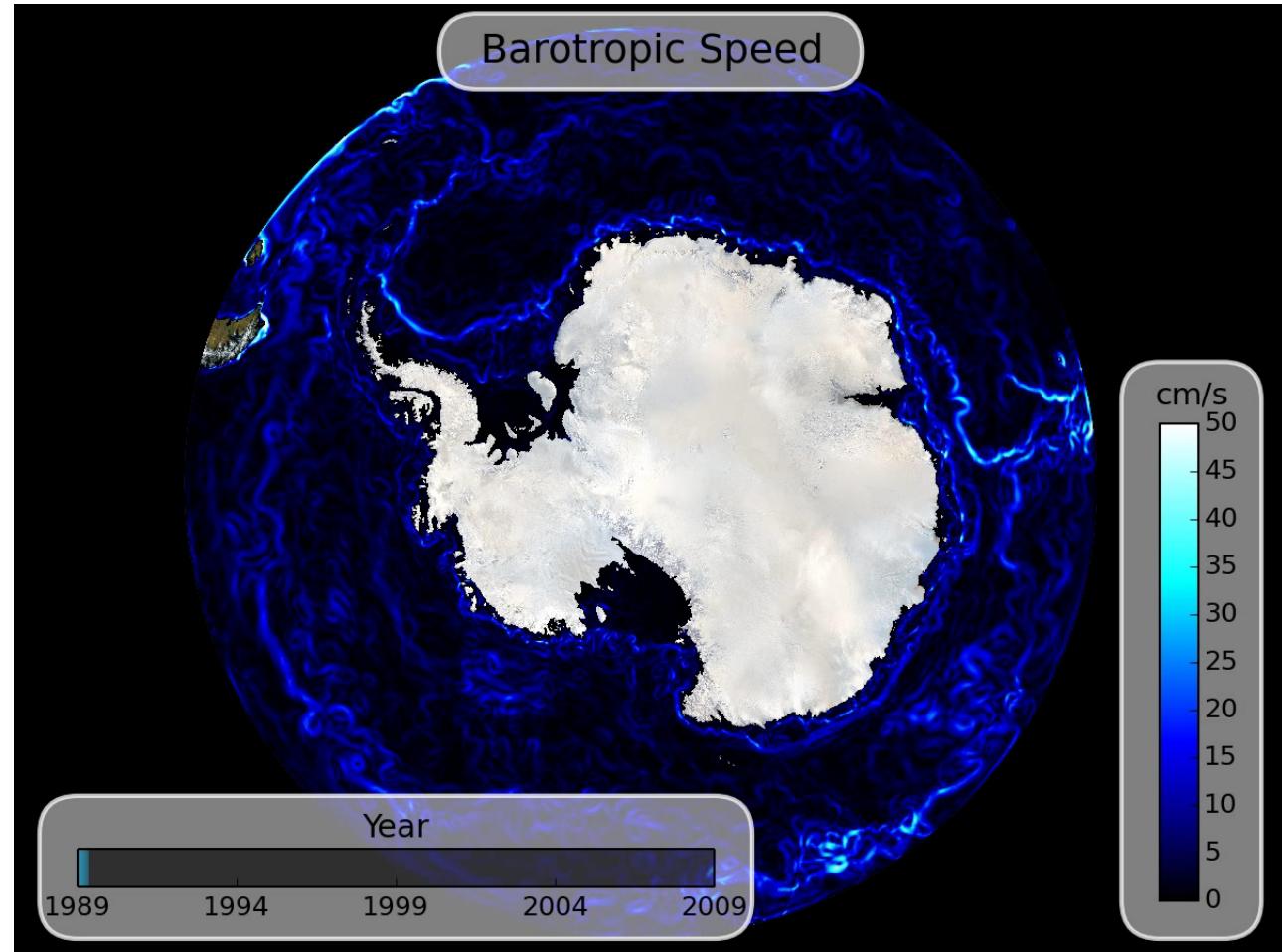
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Antarctic-Southern Ocean Simulation

POP setup:

- Regional southern ocean domain (50-85°S)
- ~5 km (0.1°) horizontal res.;
- 80 vertical levels
(10m - 250m)
- Initialize with stand-alone (3 & 20 years) run;
- Bedmap2 geometry



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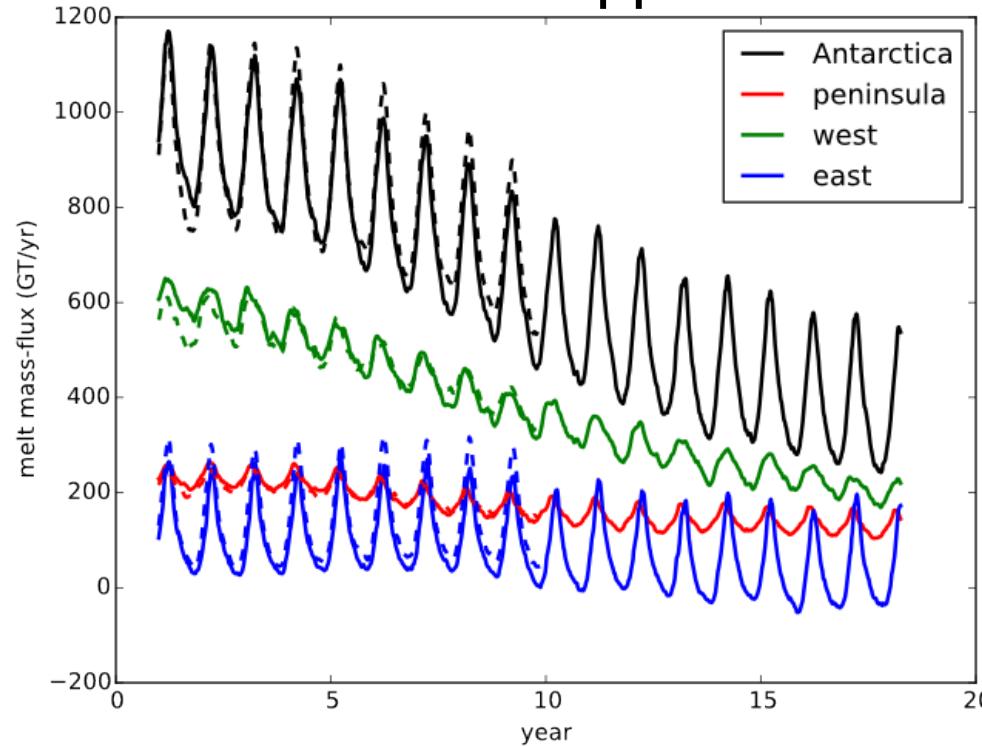
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Two forcing regimes

- LANL “Normal Year” monthly mean forcing
- CORE InterAnnual Forcing (CORE-IAF)

Normal-Year Coupled Simulations

What Happens?



- Cold bias -- Melt rates are spinning down over time (POP issue)
- Possible causes -
 - Over-stratification (too much freshwater forcing?)
 - climate forcing?
 - no sea ice model? (Regional-mode POP issue)



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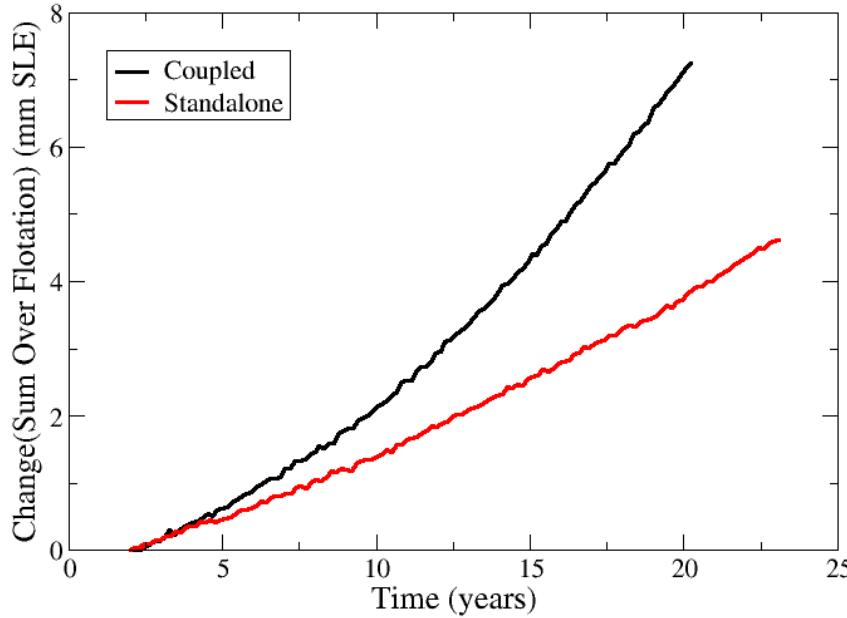
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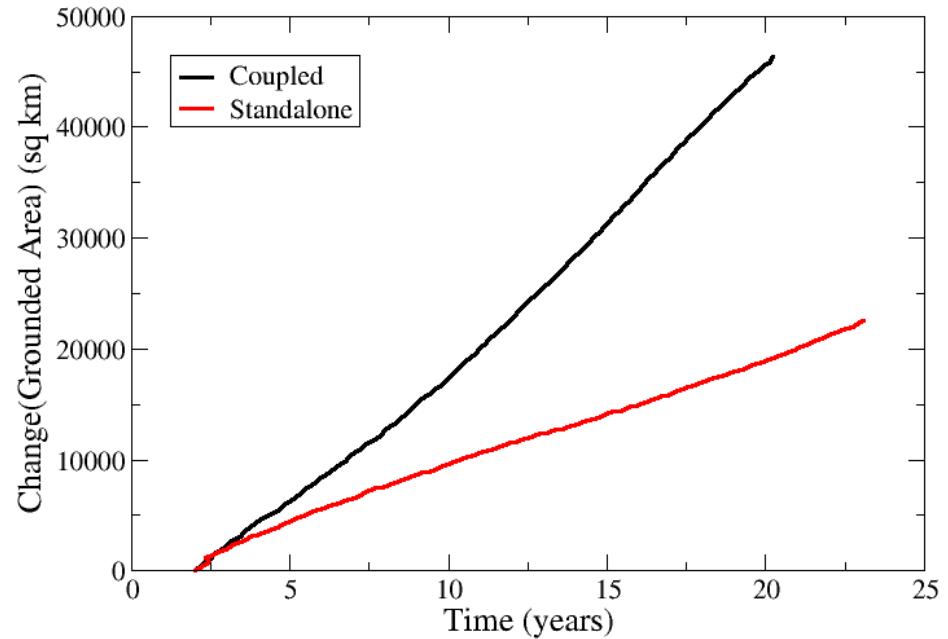
Normal-year Coupled Sims (Ice sheet)

Compare Standalone vs. Coupled runs:

Change in Ice over Flotation



Change in Grounded Area



- “Steady-state” initial condition isn’t quite (mass gain)
- Melt rates are spinning down over time (POP issue)
- **Can see effect of coupling (gains mass faster than standalone)**



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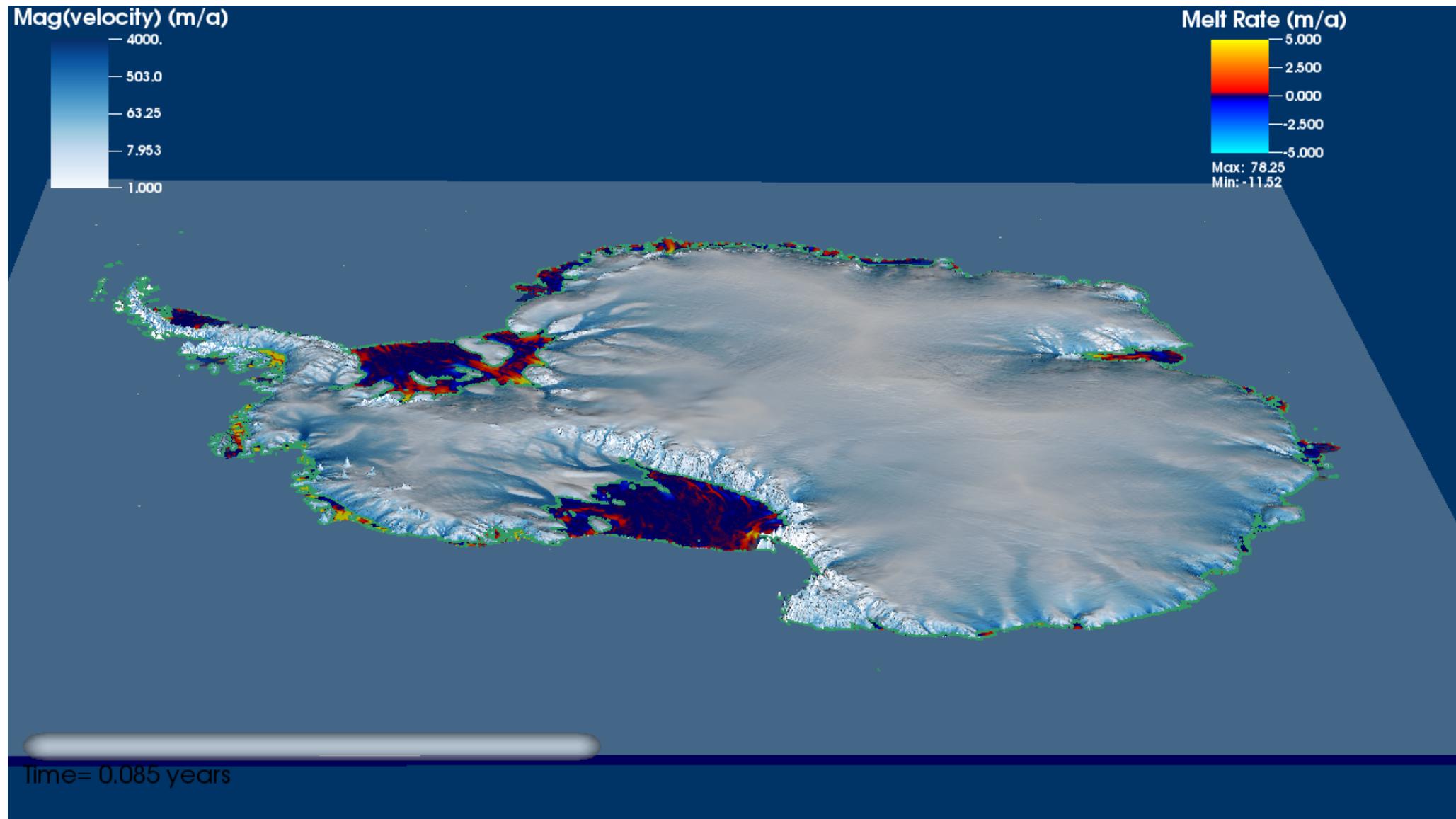
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Antarctic-Southern Ocean Coupled Sims (cont)



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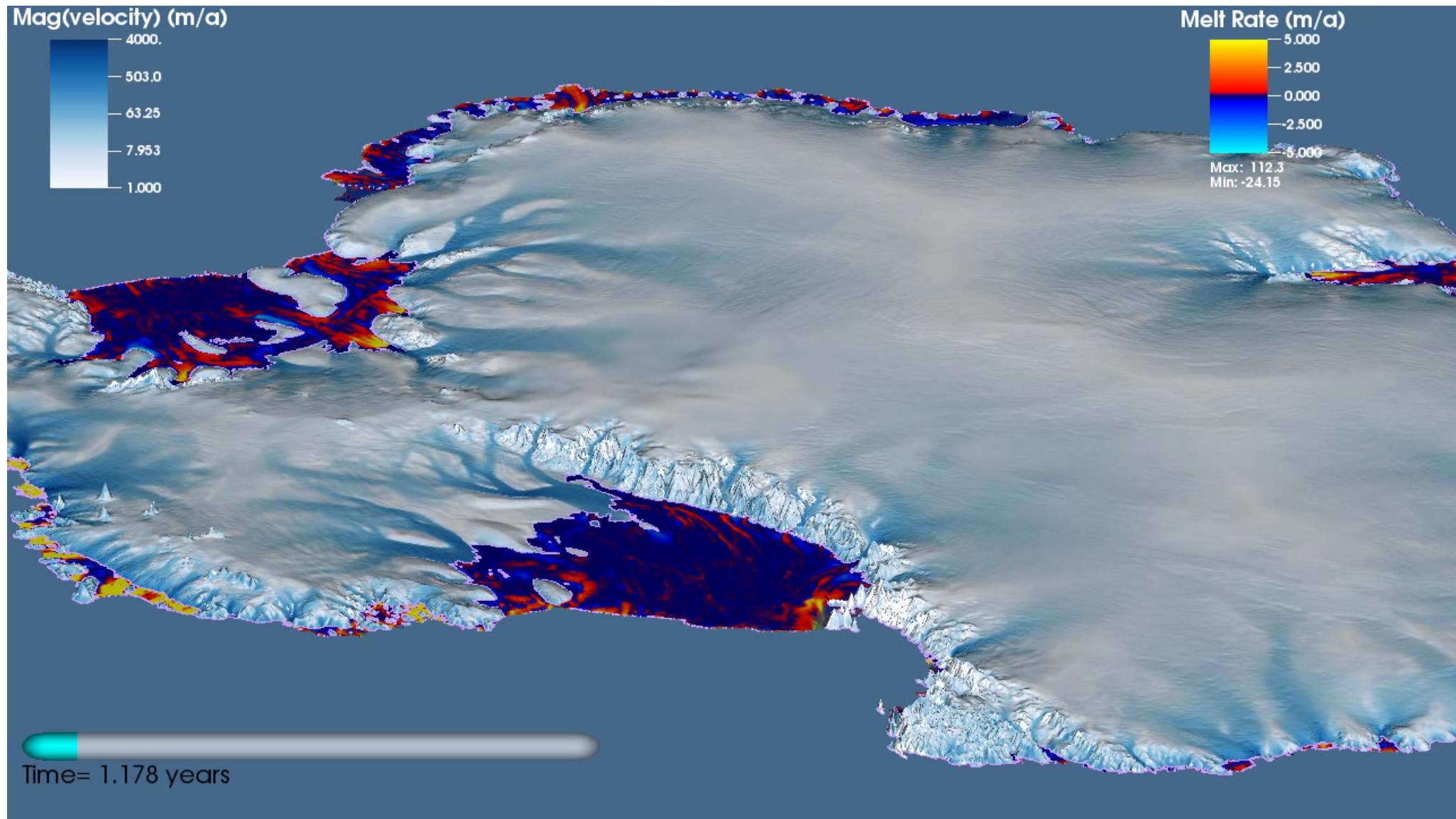
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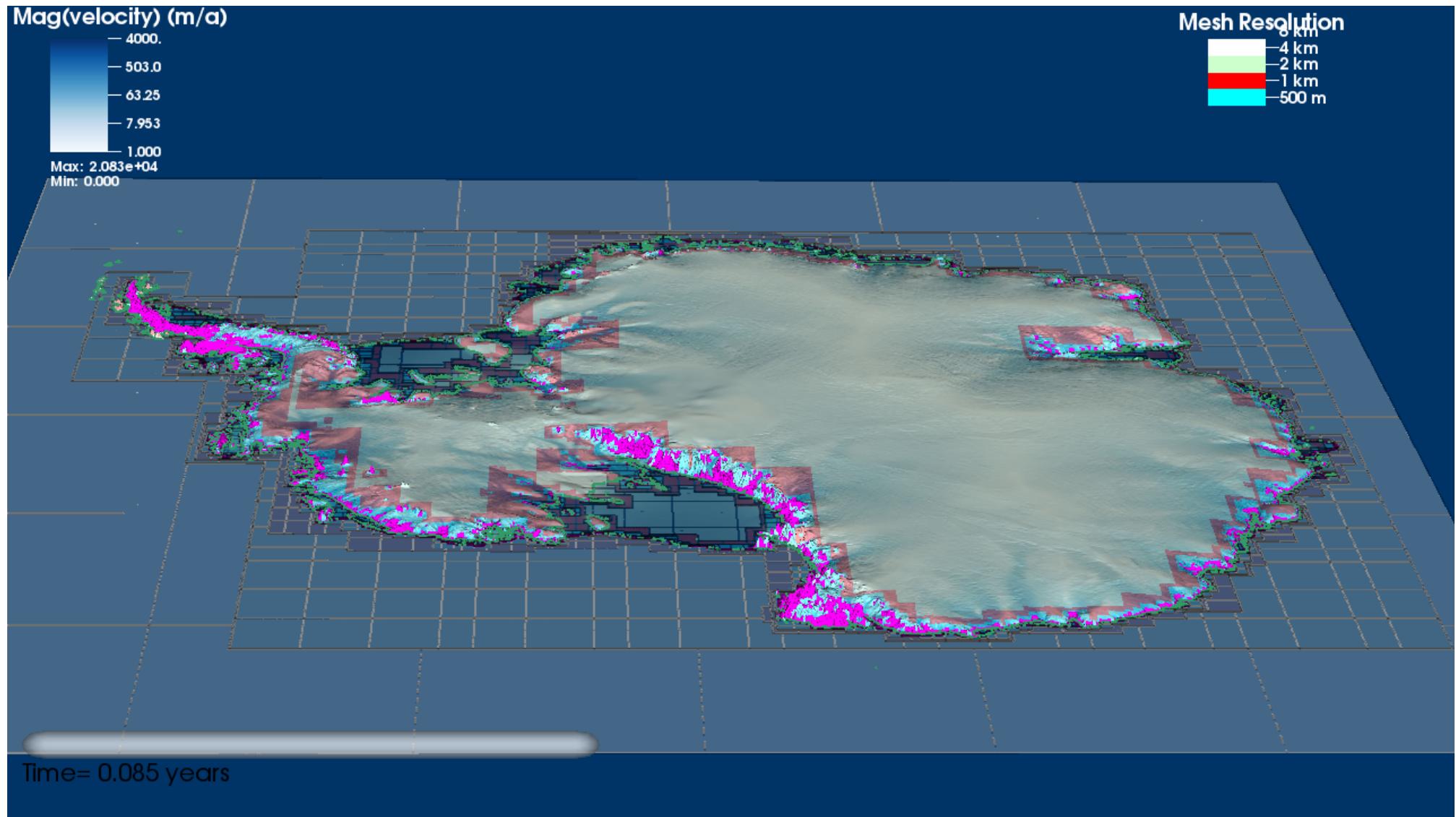
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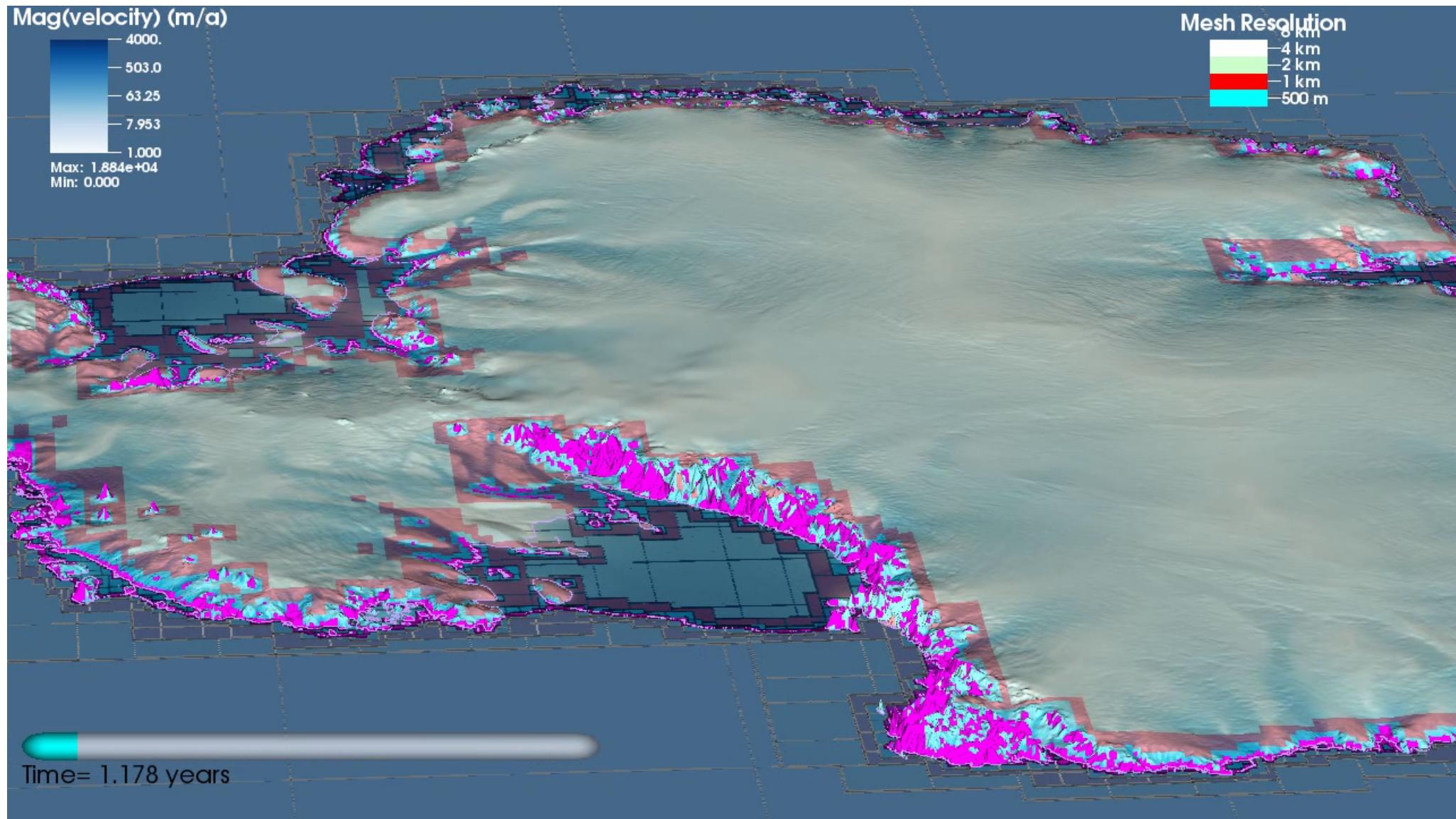
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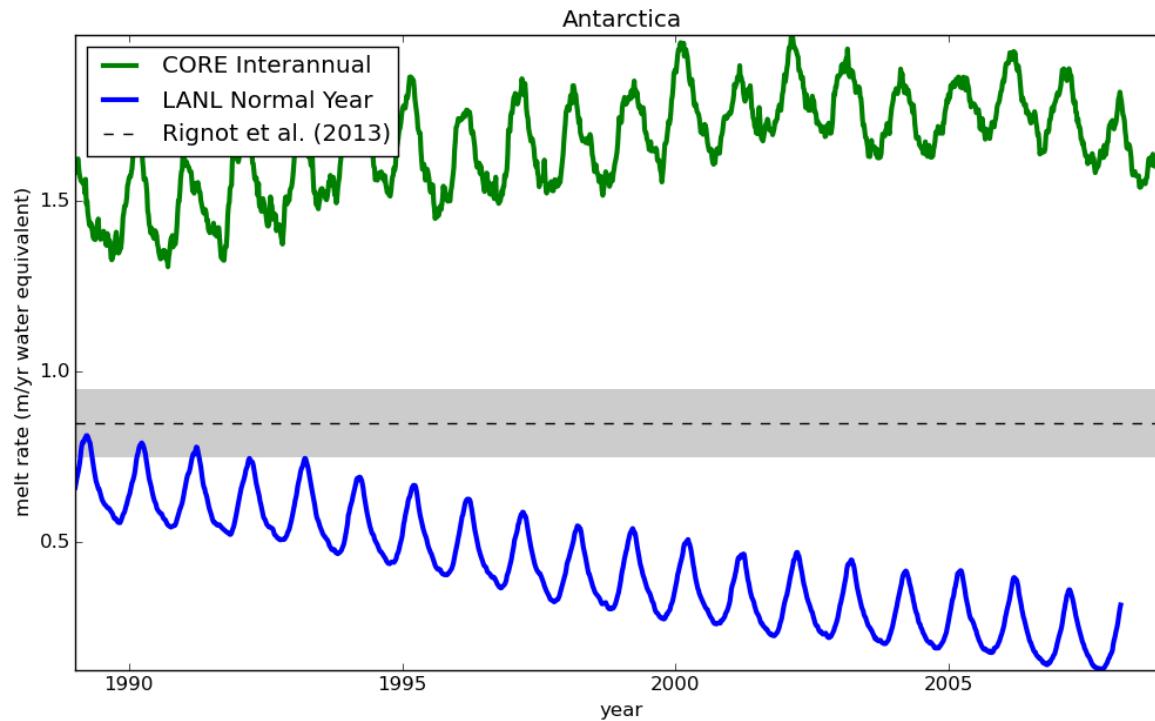
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Normal Year vs. CORE-IAF: Impact on melt rates

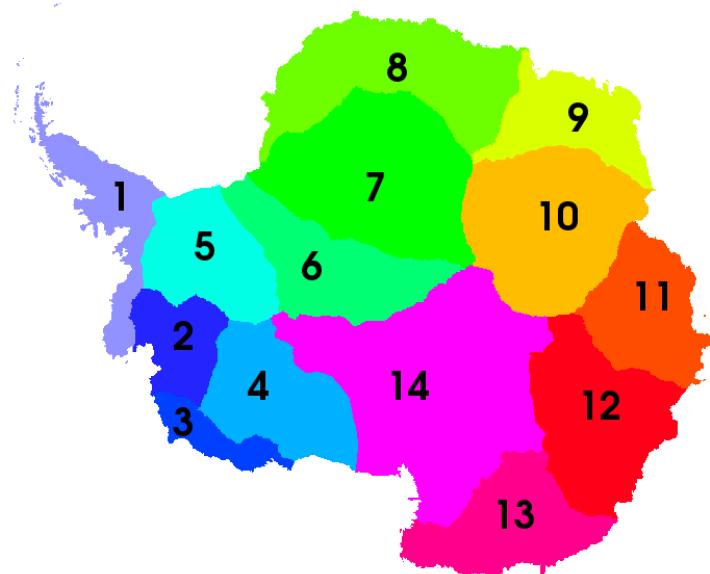


Switching to CORE-IAF forcing switches cold bias to warm...

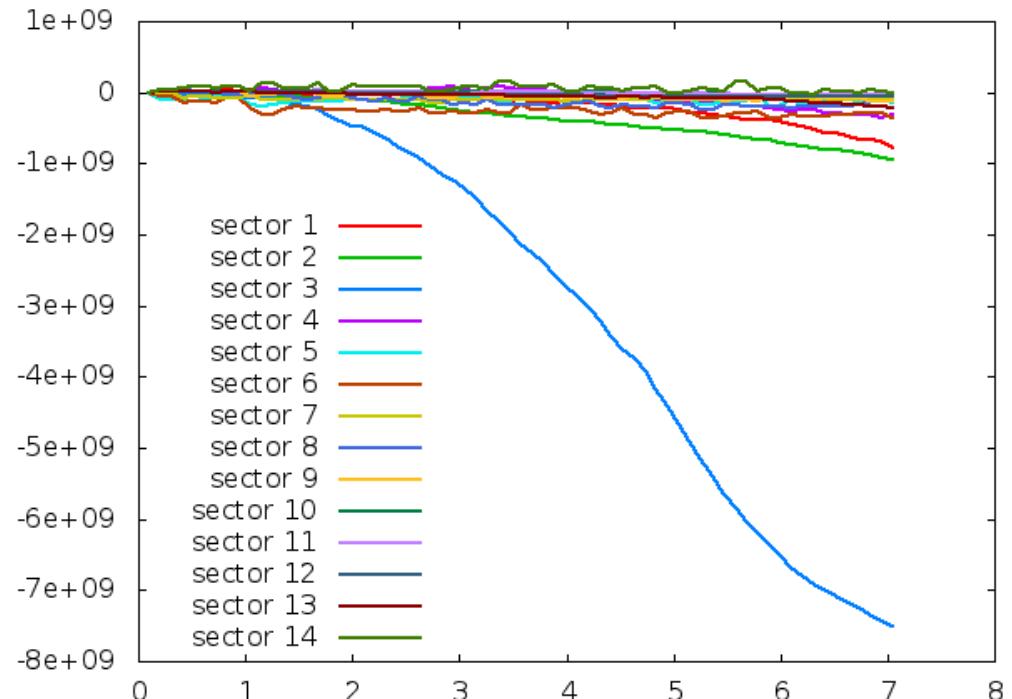
- **Mixing of CDW into upper ocean**
- Destratification from freshwater forcing? (Joakim Kjellsson's talk Tuesday)
- Lack of Dynamic Sea Ice?

Coupled Antarctica: Core-IAF

Antarctic sectors



Floating area change by sector vs. Time



- Response dominated by loss of floating area in a few sectors (**Getz!**)
- This was supposed to be the **warming** scenario
- **What happened?** (Getz sector!)



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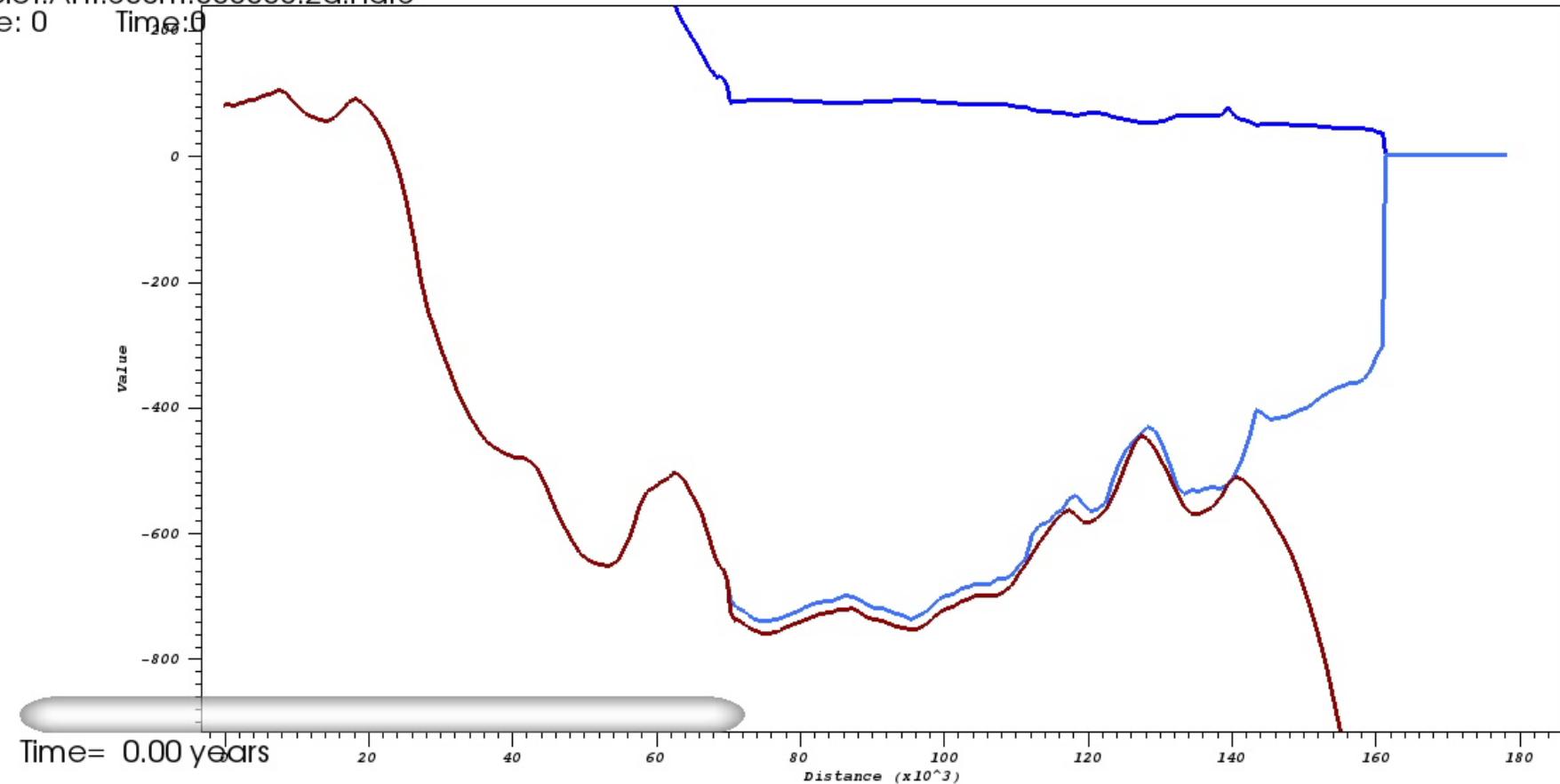


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Getz Ice shelf -- Regrounding instability (cont)

DB: plot.Ant.500m.000000.2d.hdf5
Cycle: 0 Time: 0



user: dmartin
Wed Dec 3 18:51:05 2014



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Getz Ice shelf -- Regrounding instability (cont)

What happened?

- Bedmap2 - poorly constrained subshelf bathymetry
 - “Made stuff up” -- reasonable from the ice-sheet perspective
 - Resulted in very thin (< 100m) subshelf cavities under the ice
- Nominal/standalone POP2x melt rates fairly high
- Large synthetic accumulation field to balance melt and keep shelf in steady state
- Time-dependent runs - *instability*
 - Small relative fluctuations in melt-rate forcing can result in thickness changes which are $O($ cavity thickness)
 - Localized grounding
 - Subshelf melting turns off - unbalanced (and large!) accumulation
 - Leads to more regrounding -> more unbalanced melt....



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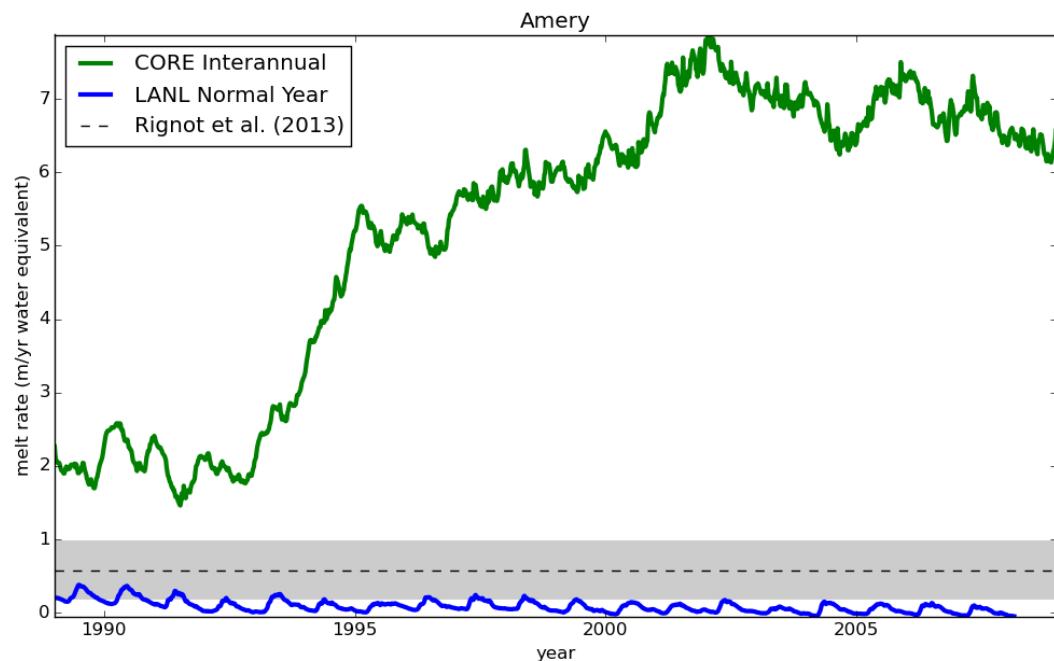


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Warmwater incursion - Amery

- Warmwater incursion in Amery basin
- Increased melt rate - front reaches end of cavity in 9-10 years
- Moderate GL retreat



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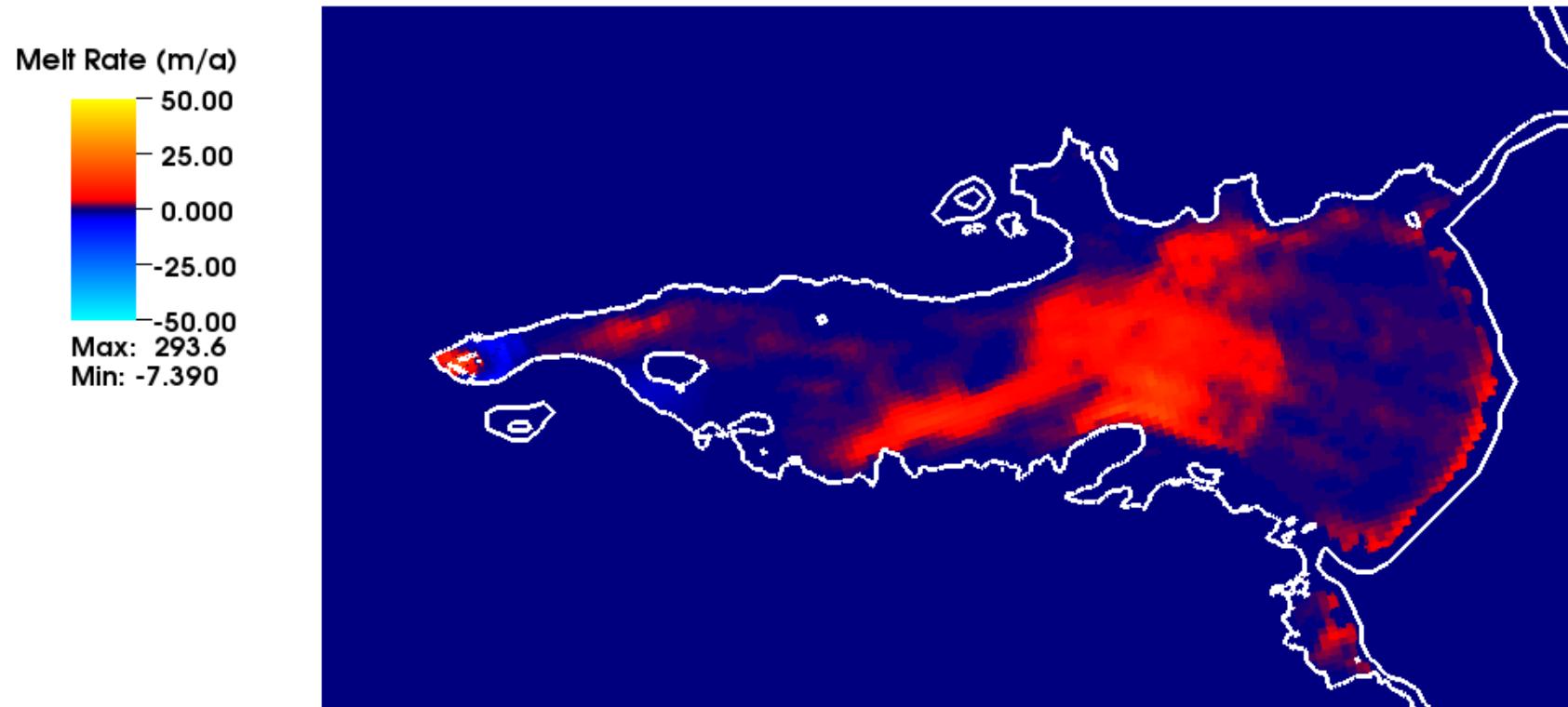
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Warmwater Incursion - Amery (cont)



Time= 0.00 years



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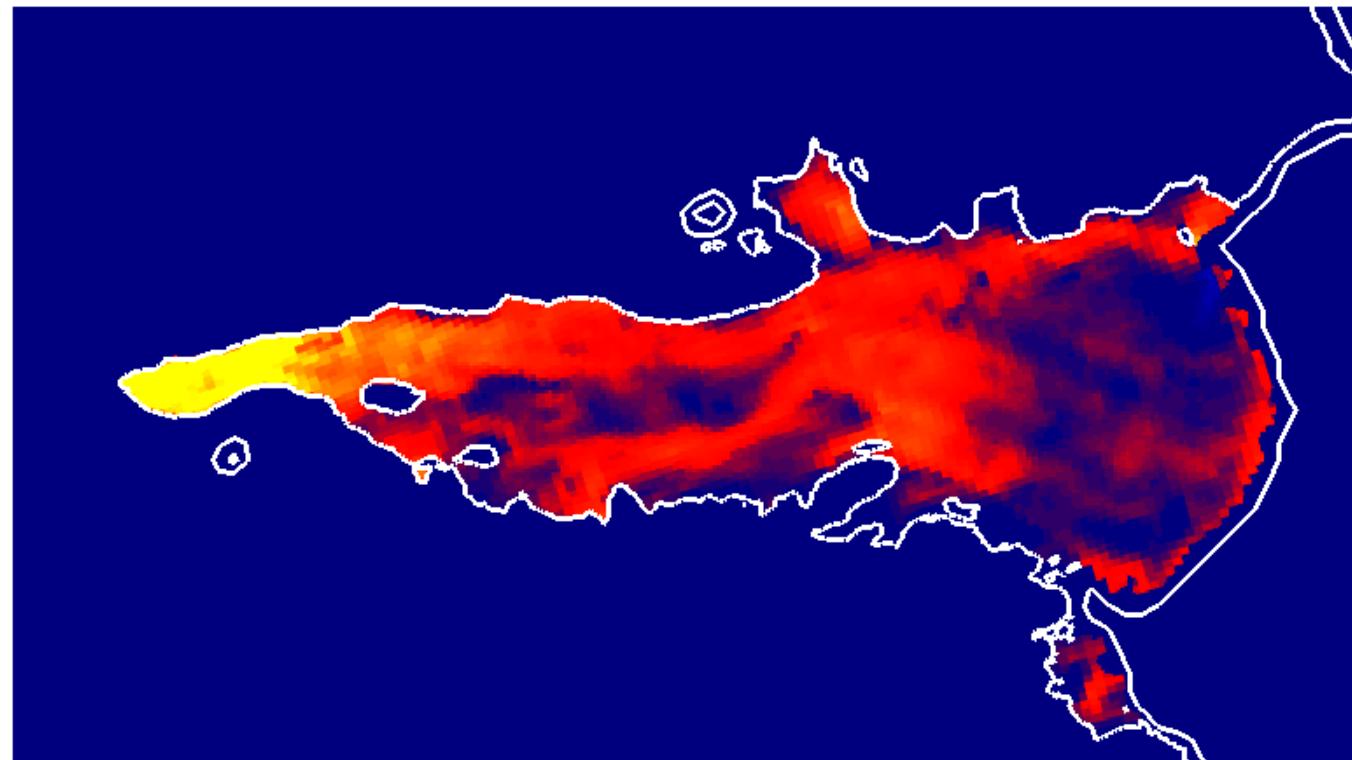
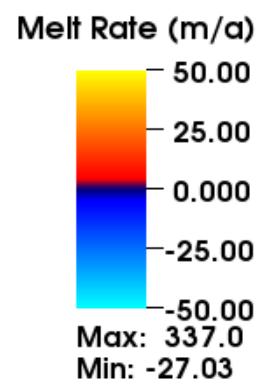
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Warmwater Incursion - Amery (cont)



Time= 21.00 years



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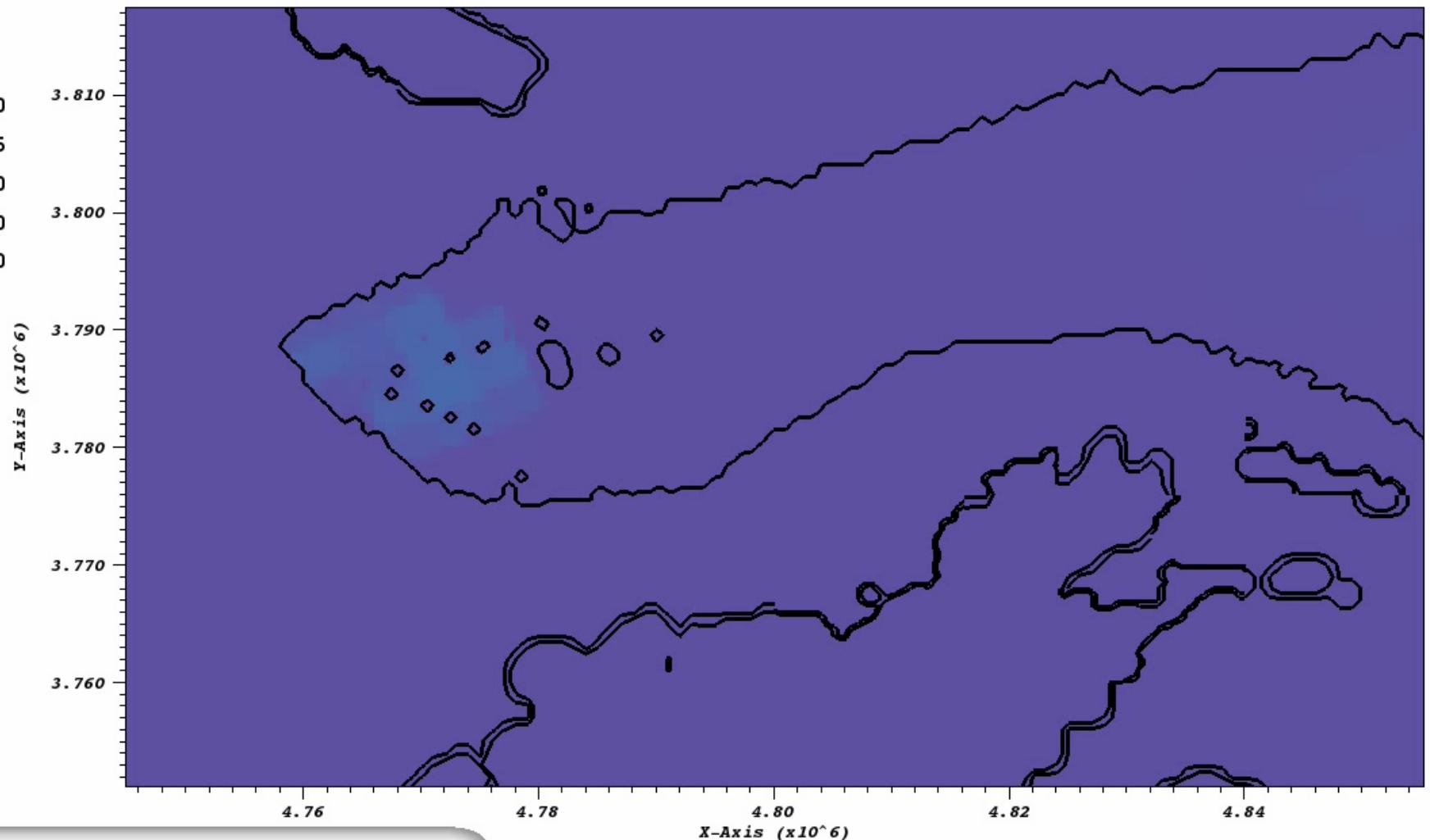


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Warmwater incursion - Amery (cont)

Pseudocolor
Var: melt
330.0
247.5
165.0
82.50
0.000
Max: 254.9
Min: -16.21



Time= 0.58 years



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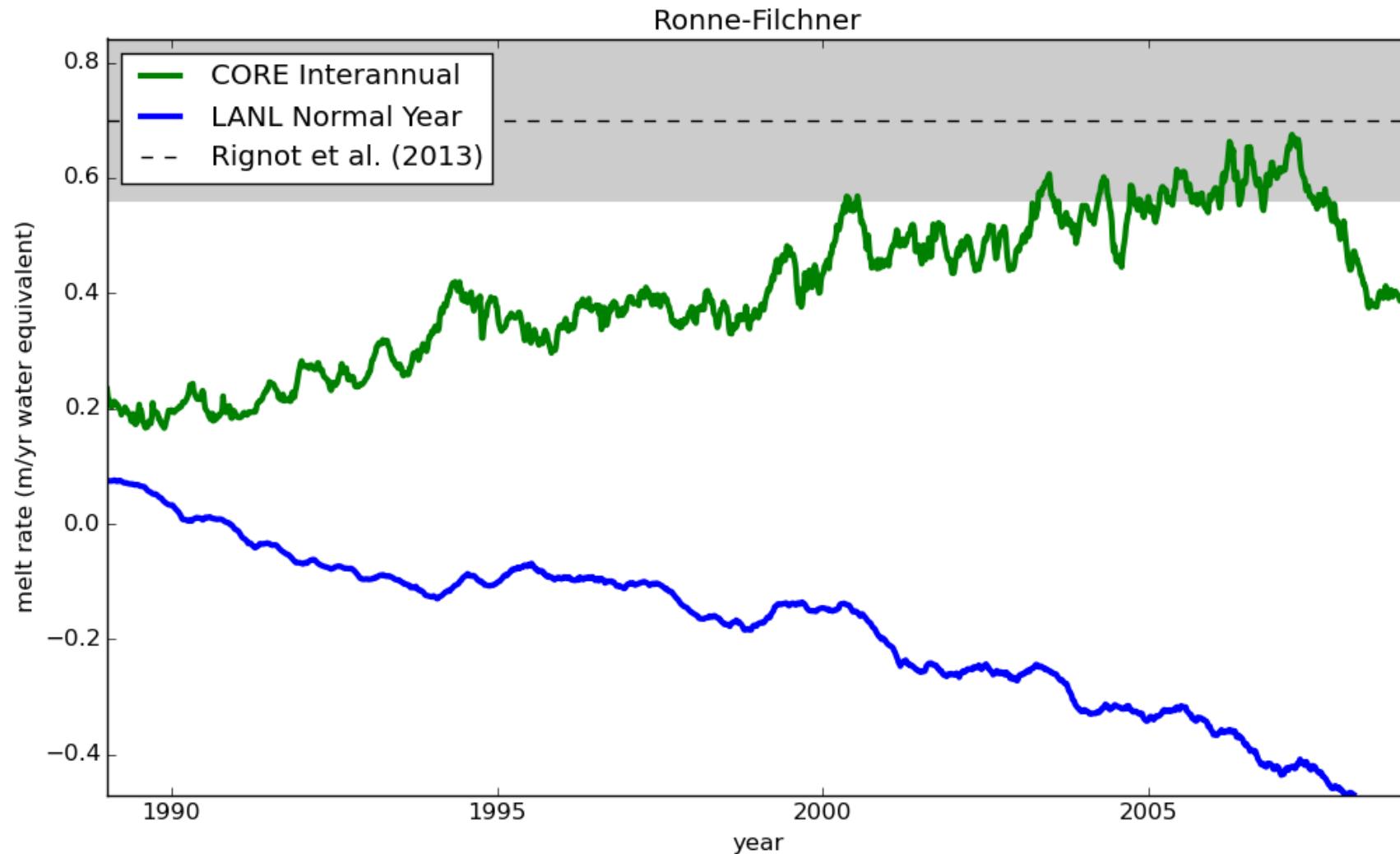
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Ronne-Filchner



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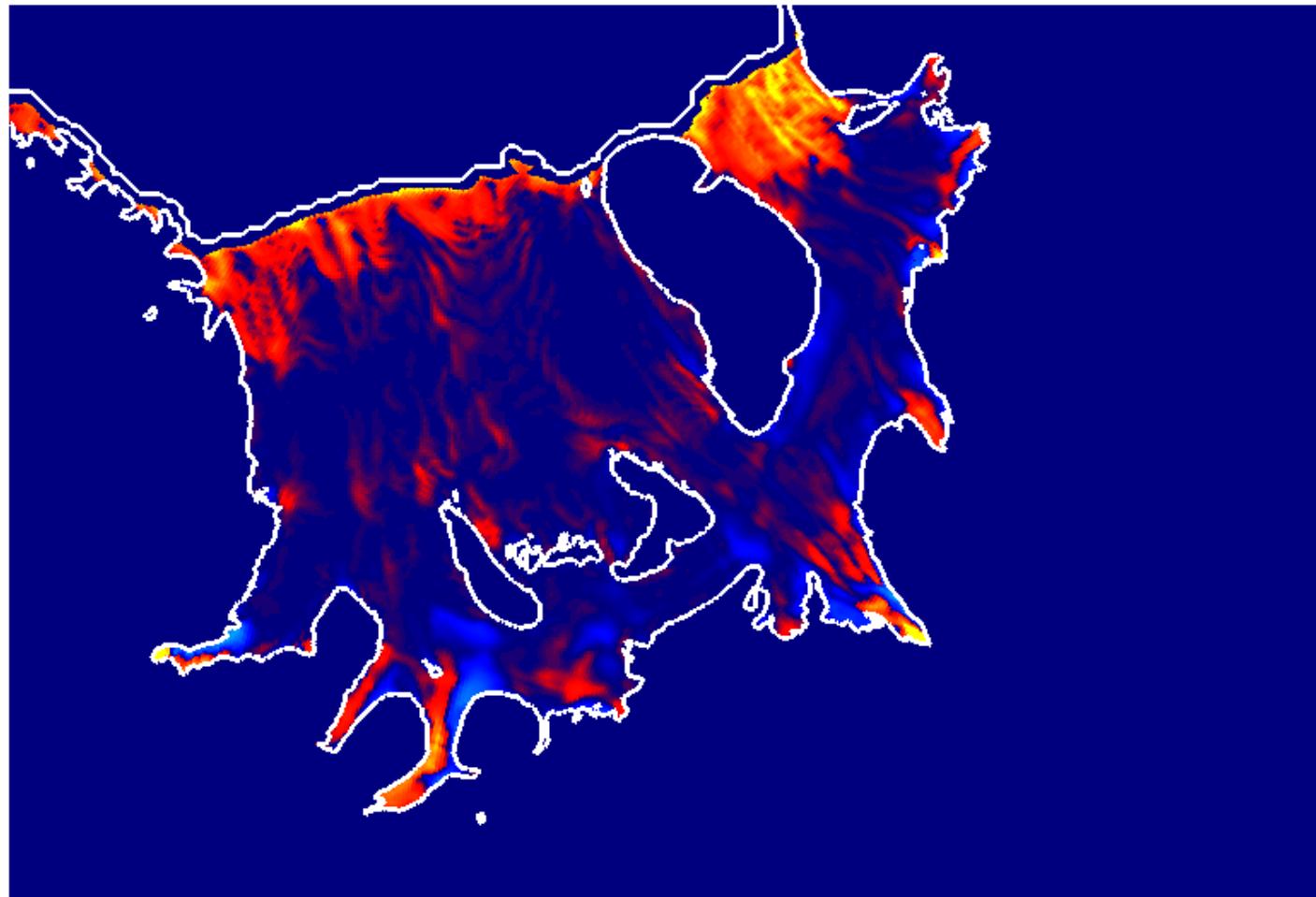
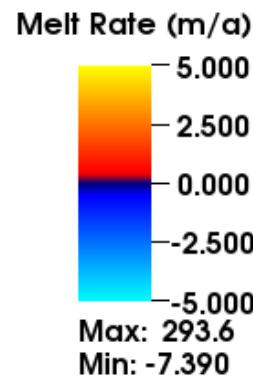
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Ronne-Filchner Ice Shelf



Time= 0.00 years



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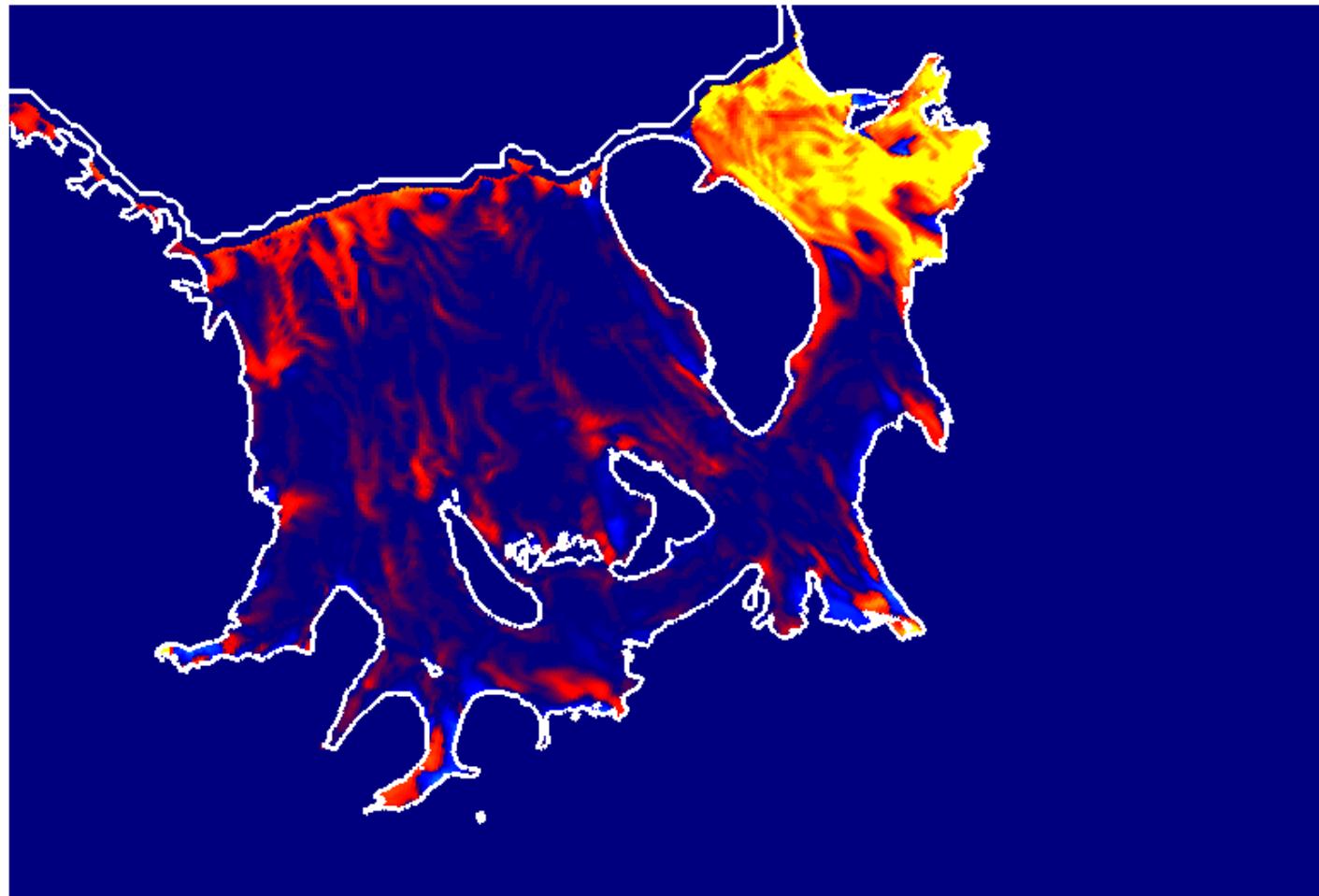
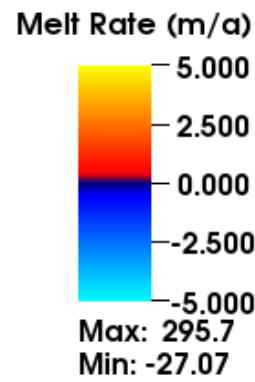
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Ronne-Filchner Ice Shelf



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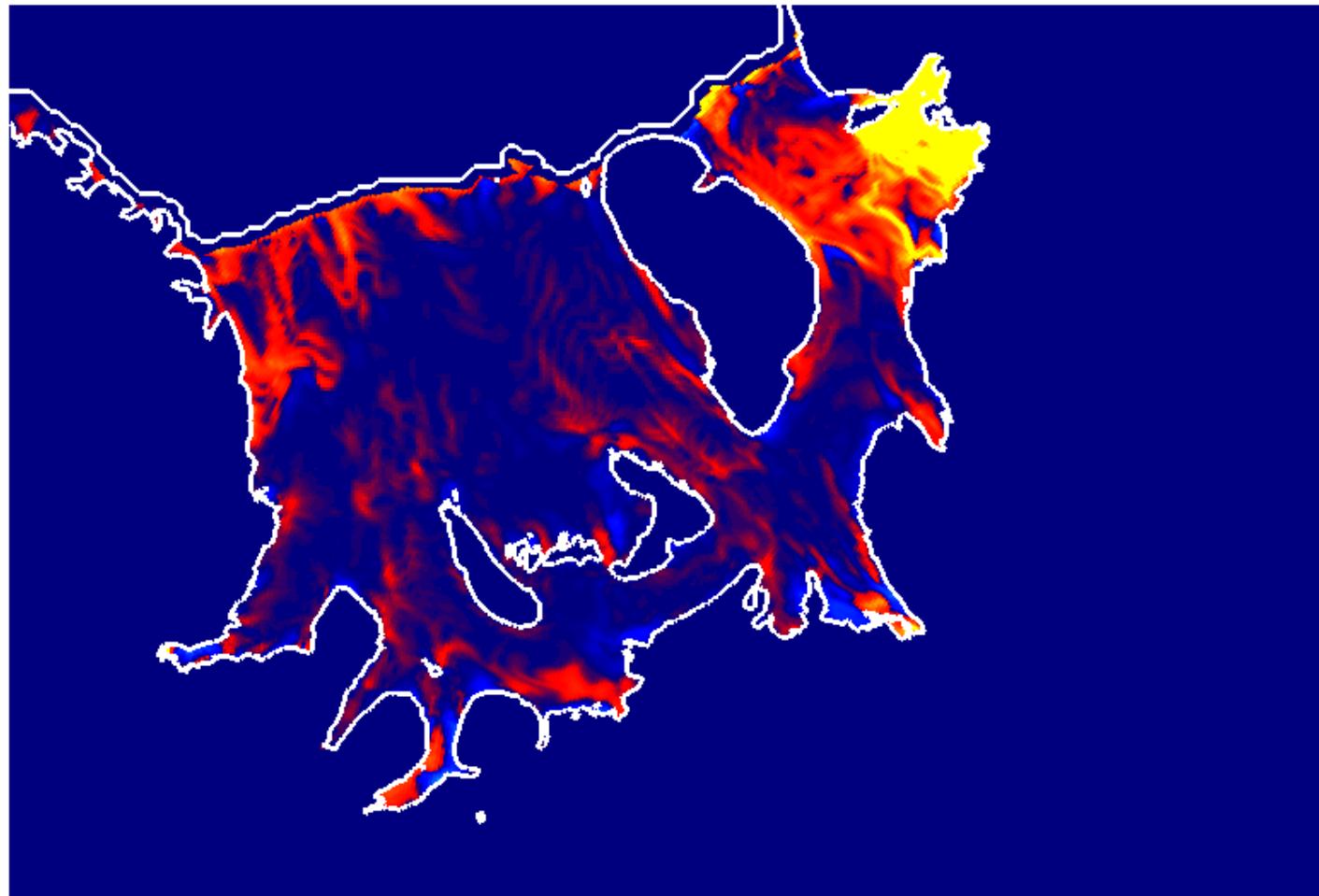
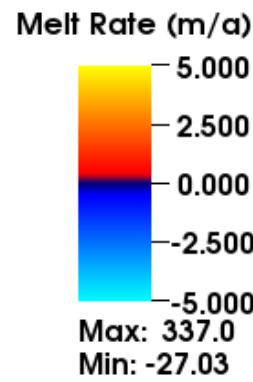
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Ronne-Filchner Ice Shelf



Time= 21.00 years



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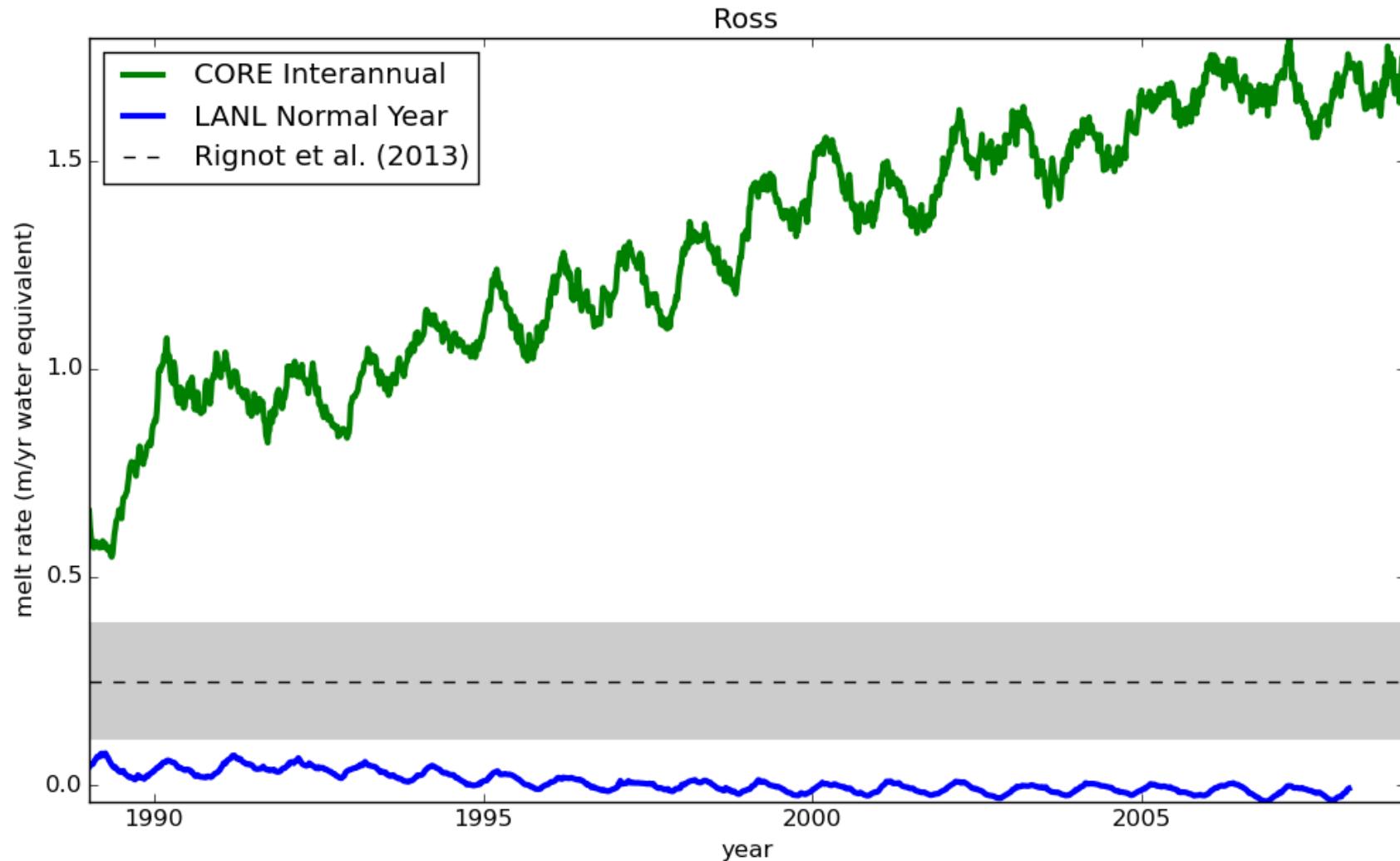
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Ross Ice Shelf



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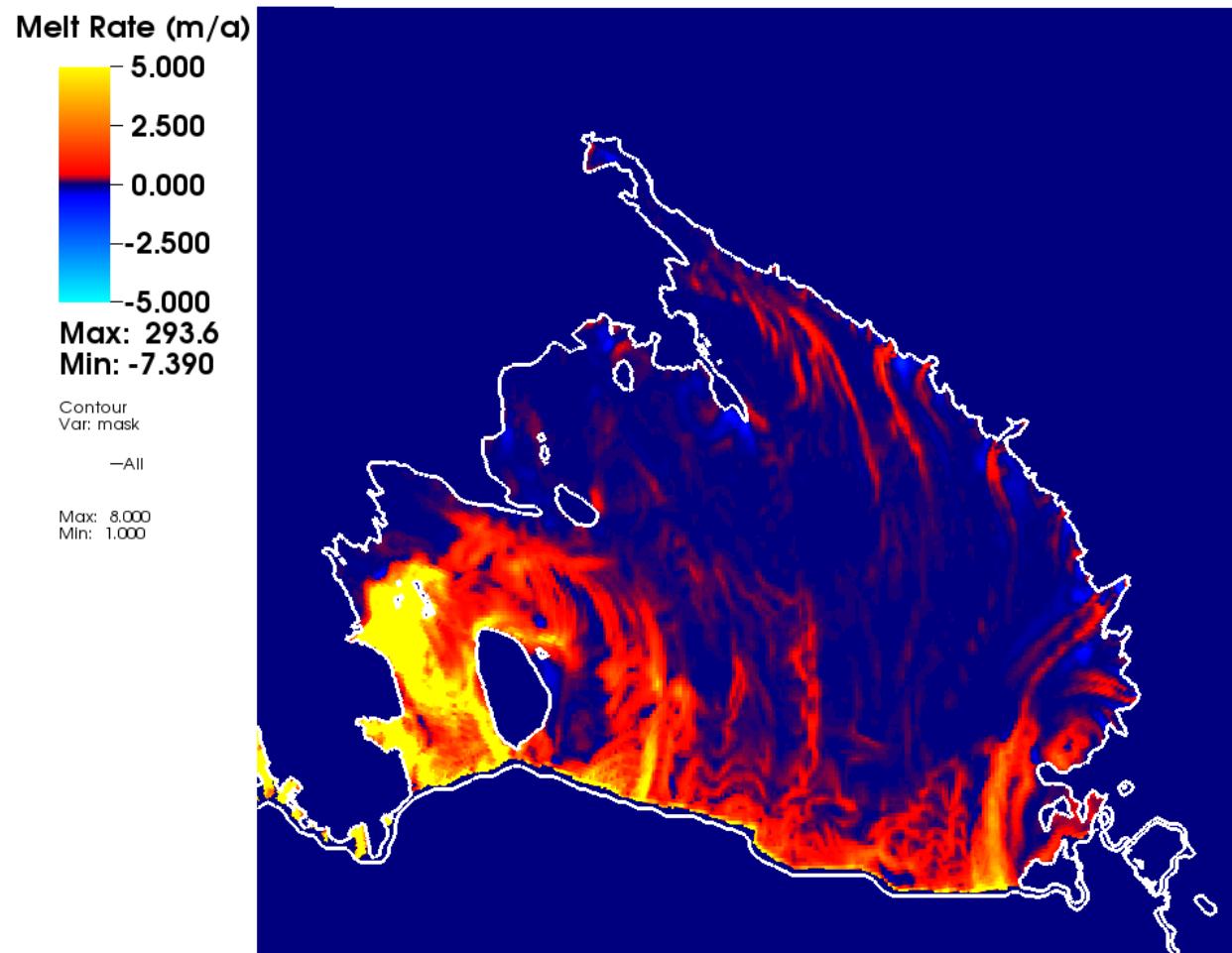
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Time= 0.00 years



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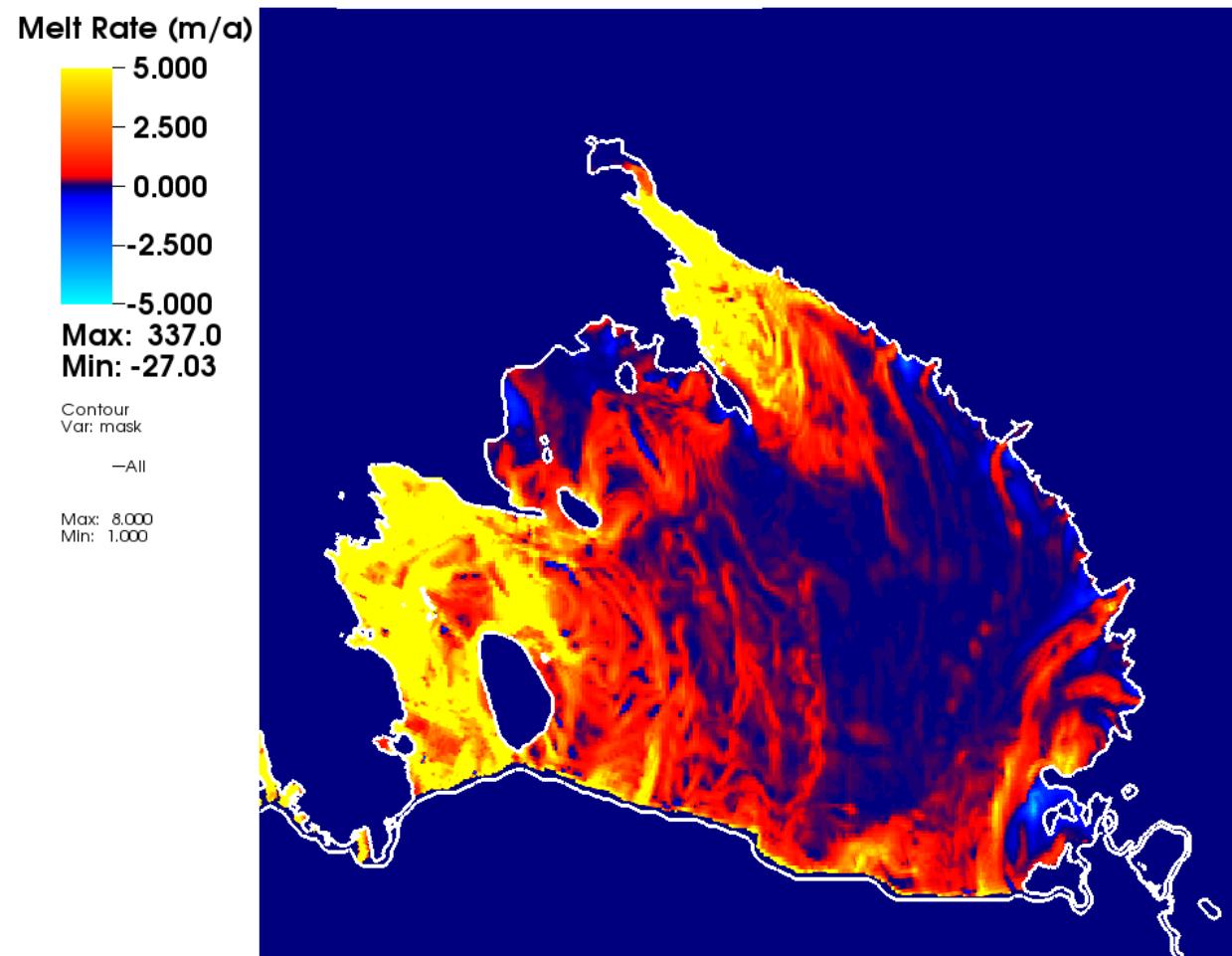
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Time= 21.00 years



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Future work

- Fix issues exposed during coupled run and try again.
 - Deepen bathymetry in problem regions (RTOPO1)
 - BISICLES initial condition -- realistic (Arthern?) SMB
- More realistic climatology/forcing leading to “real” projections



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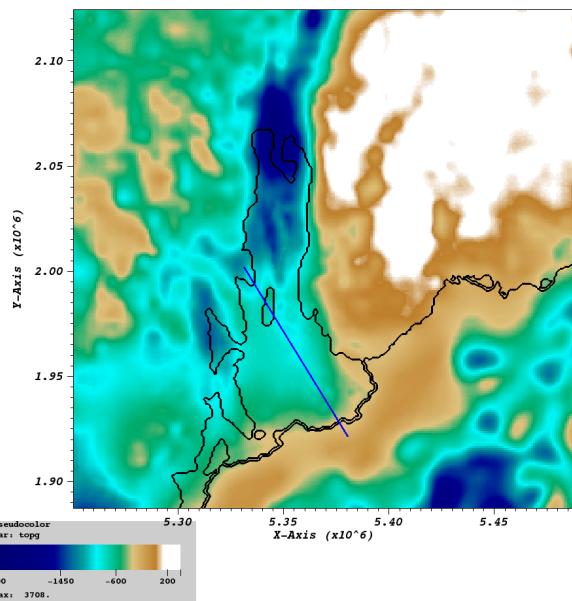
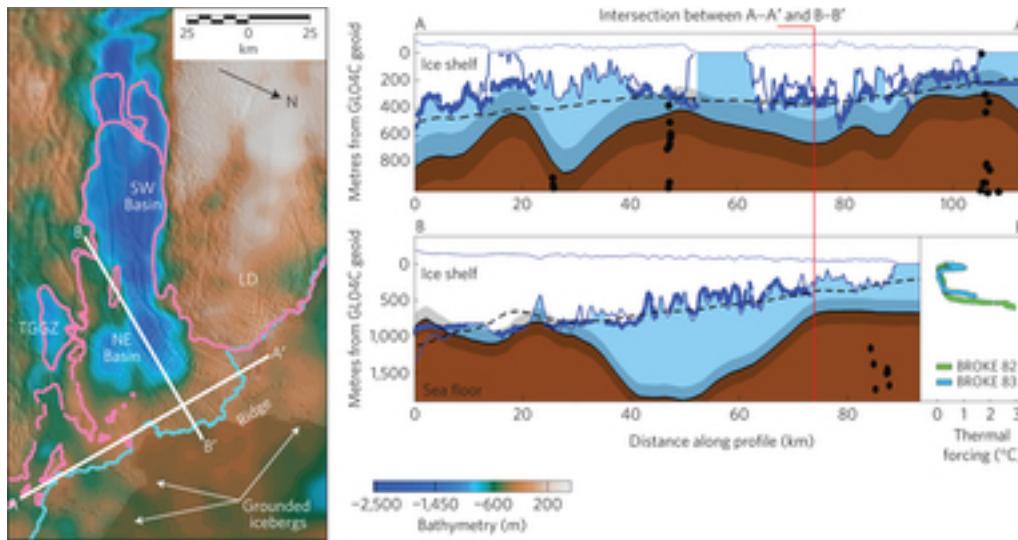
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Deepening bathymetry -- Totten



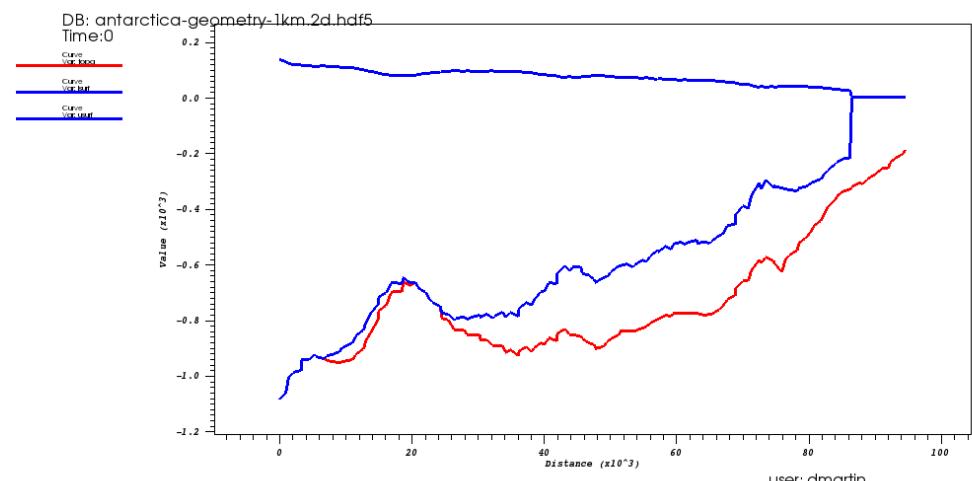
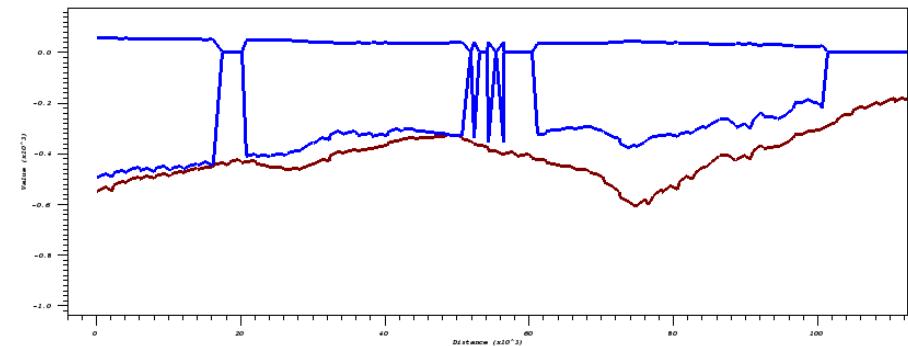
LETTERS

PUBLISHED ONLINE: 16 MARCH 2015 | DOI: 10.1038/NGEO2388

nature
geoscience

Ocean access to a cavity beneath Totten Glacier in East Antarctica

J. S. Greenbaum^{1*}, D. D. Blankenship¹, D. A. Young¹, T. G. Richter¹, J. L. Roberts^{2,3}, A. R. A. Aitken⁴, B. Legresy^{2,5,6}, D. M. Schroeder⁷, R. C. Warner^{2,3}, T. D. van Ommen^{2,3} and M. J. Siegert⁸



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Wed Mar 25 01:11:32 2015



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Thank you!



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Extras



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Computational Cost

- Run on NERSC's Edison
- For each 1-month coupling interval:
 - POP: 1080 processors, 50 min
 - BISICLES: 384 processors, ~30 min
 - Extra “BISICLES” time used to set up POP grids for next step
- Total:
 $1464 \text{ proc} \times 50 \text{ min} = \sim 15,000 \text{ CPU-hours/simulation year}$
(~1.5M CPU-hours/100 years)



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Motivation: Projecting future Sea Level Rise

- Potentially large Antarctic contributions to SLR resulting from marine ice sheet instability, particularly from WAIS.
- Climate driver: subshelf melting driven by warm(ing) ocean water intruding into subshelf cavities.
- Paleorecord implies that WAIS has deglaciated in the past.



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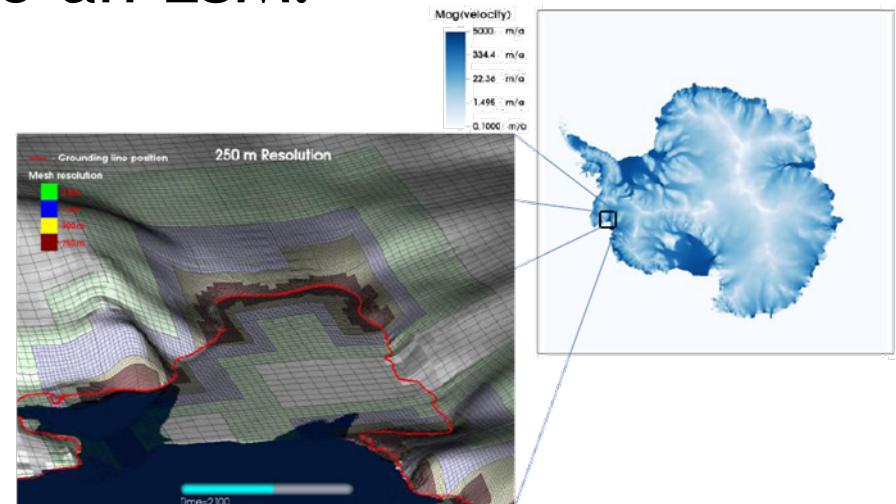
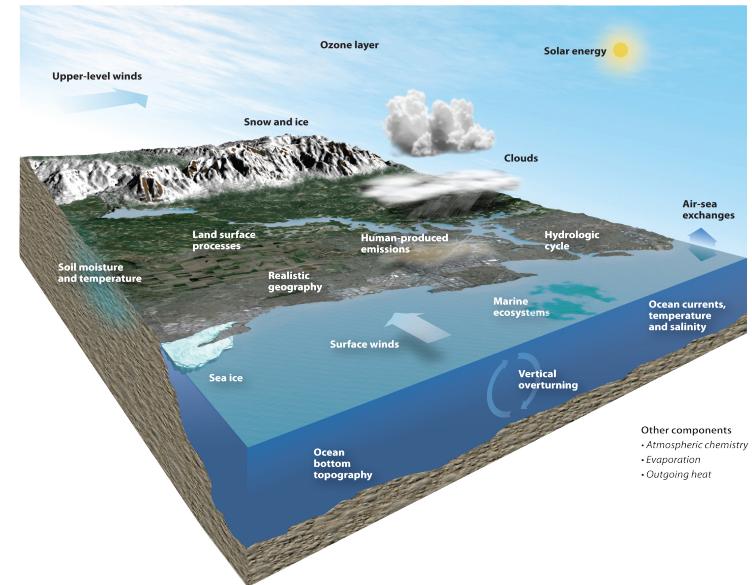


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Big Picture -- target

- ☒ Aiming for coupled ice-sheet-ocean modeling in ESM
- ☒ Multi-decadal to century timescales
- ☒ Target resolution:
 - ☒ Ocean: 0.1 Degree
 - ☒ Ice-sheet: 500 m (adaptive)
- ☒ Why put an ice-sheet model into an ESM?
 - ☒ fuller picture of sea-level change
 - ☒ feedbacks may matter on timescales of years, not just millennia



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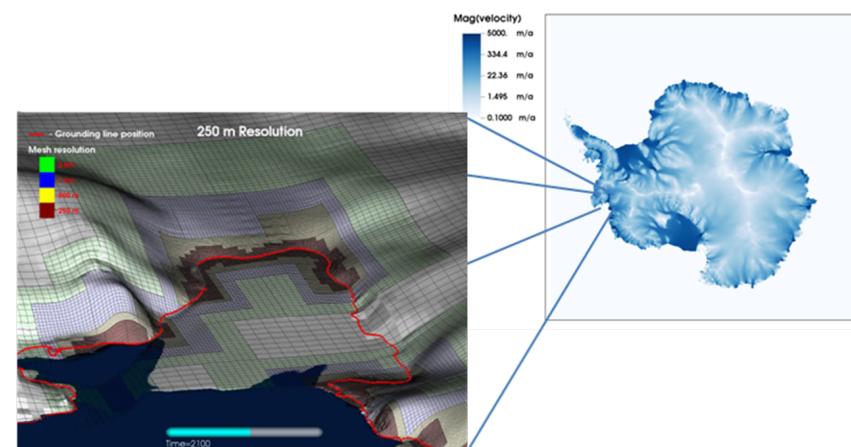
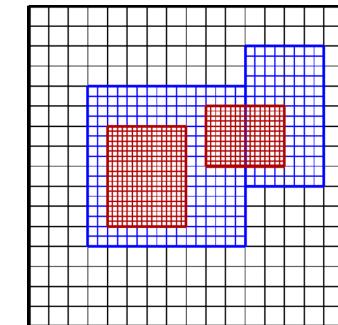


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BISICLES Ice Sheet Model

- Scalable adaptive mesh refinement (AMR) ice sheet model
 - Dynamic local refinement of mesh to improve accuracy
- Chombo AMR framework for block-structured AMR
 - Support for AMR discretizations
 - Scalable solvers
 - Developed at LBNL
 - DOE ASCR supported (FASTMath)
- Collaboration with Bristol (U.K.) and LANL
- Variant of “L1L2” model
(Schoof and Hindmarsh, 2009)
- Coupled to Community Ice Sheet Model (CISM).
- Users in Berkeley, Bristol, Beijing, Brussels, and Berlin...



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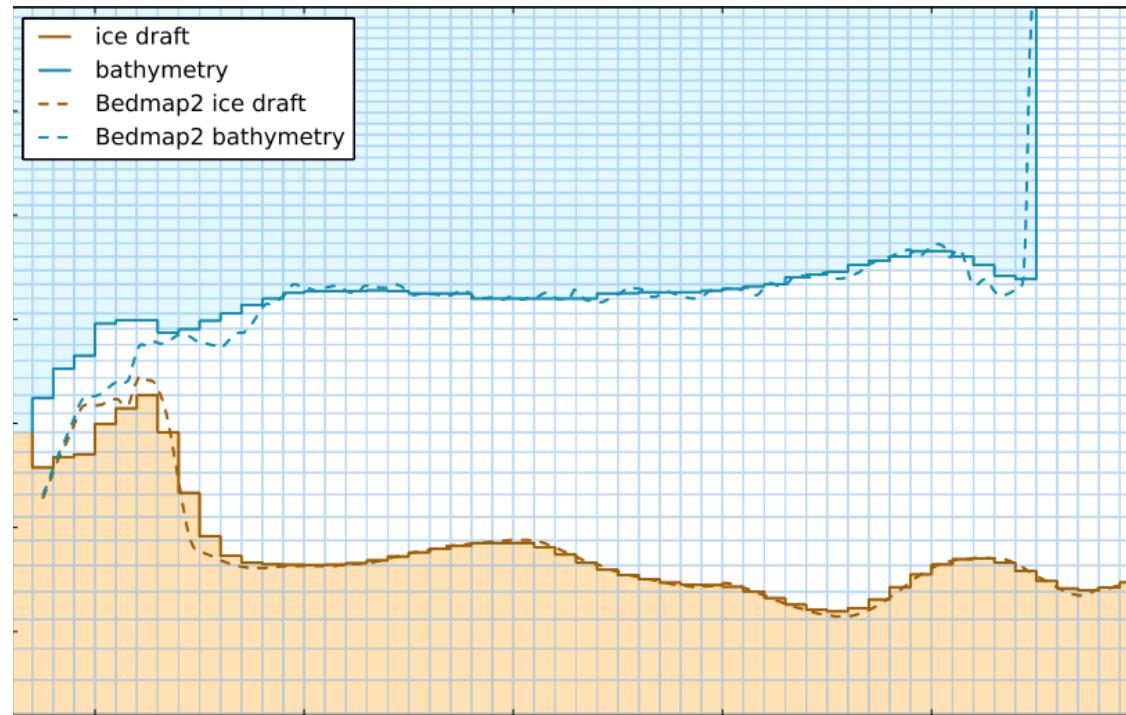


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POP and Ice Shelves

- Parallel Ocean Program (POP)
Version 2
 - Ocean model of the Community Earth System Model (CESM)
 - z-level, hydrostatic, Boussinesq
- Modified for Ice shelves:
 - partial top cells
 - boundary-layer method of Losch (2008)
- Melt rates computed by POP:
 - sensitive to vertical resolution
 - nearly insensitive to transfer coefficients, tidal velocity, drag coefficient



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Issues emerging from 1st coupled Antarctic Runs

- Fixed POP error in freezing calculation.
 - (resulted in overestimated refreezing)
- POP cold bias (spin-down of melt rates)
- Issue with artificial shelf-cavity geometry in Bedmap2
 - Bedmap2 specifically mentions Getz, Totten, Shackleton
 - Very thin subshelf cavities (constant 20 m!) result in high sensitivity to regrounding
 - Interacted with POP Thresholding cavity thickness
- Need better initialization



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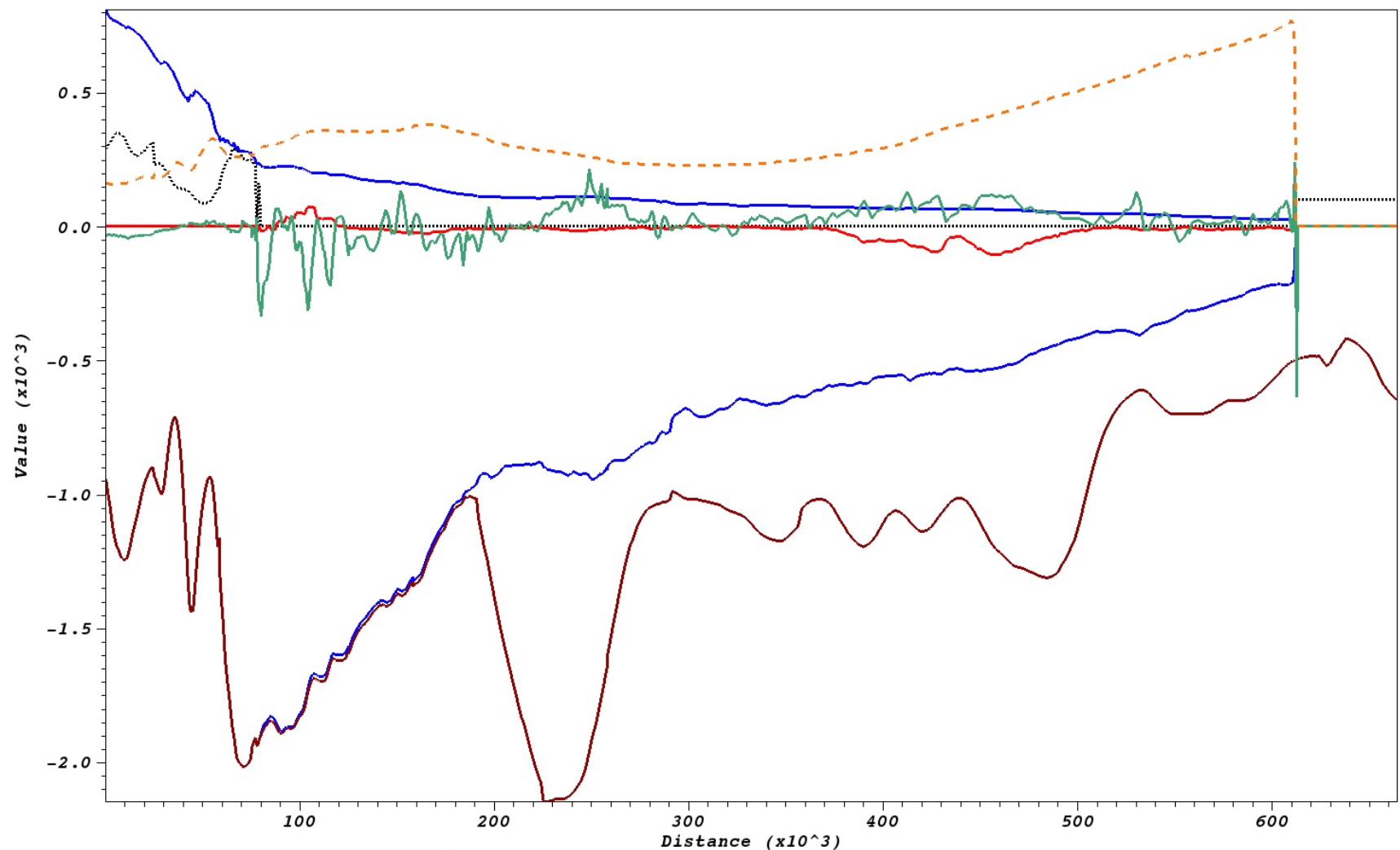
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Warmwater incursion - Amery (cont)



Time= 0.00 years



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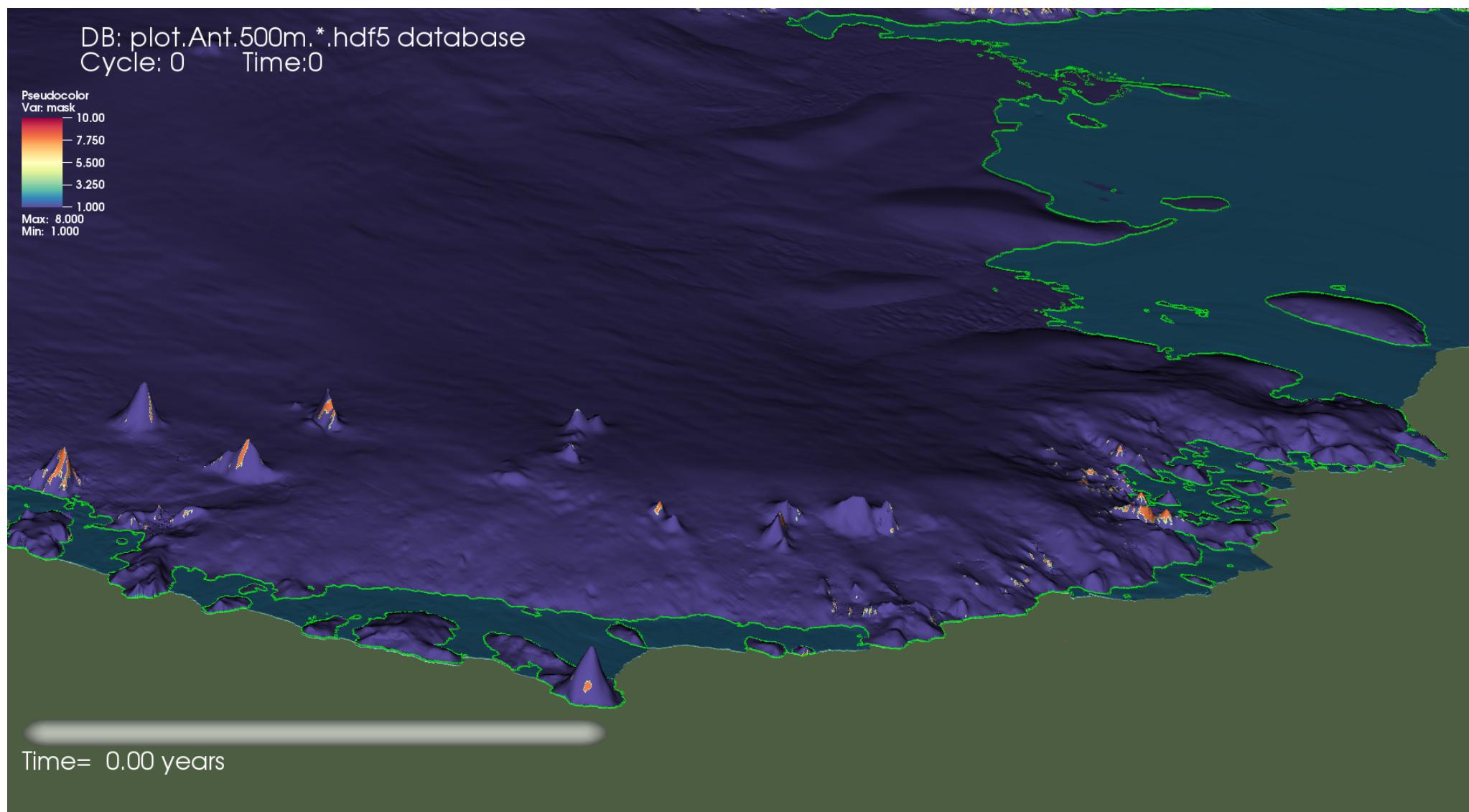
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Getz Ice Shelf - Regrounding Instability



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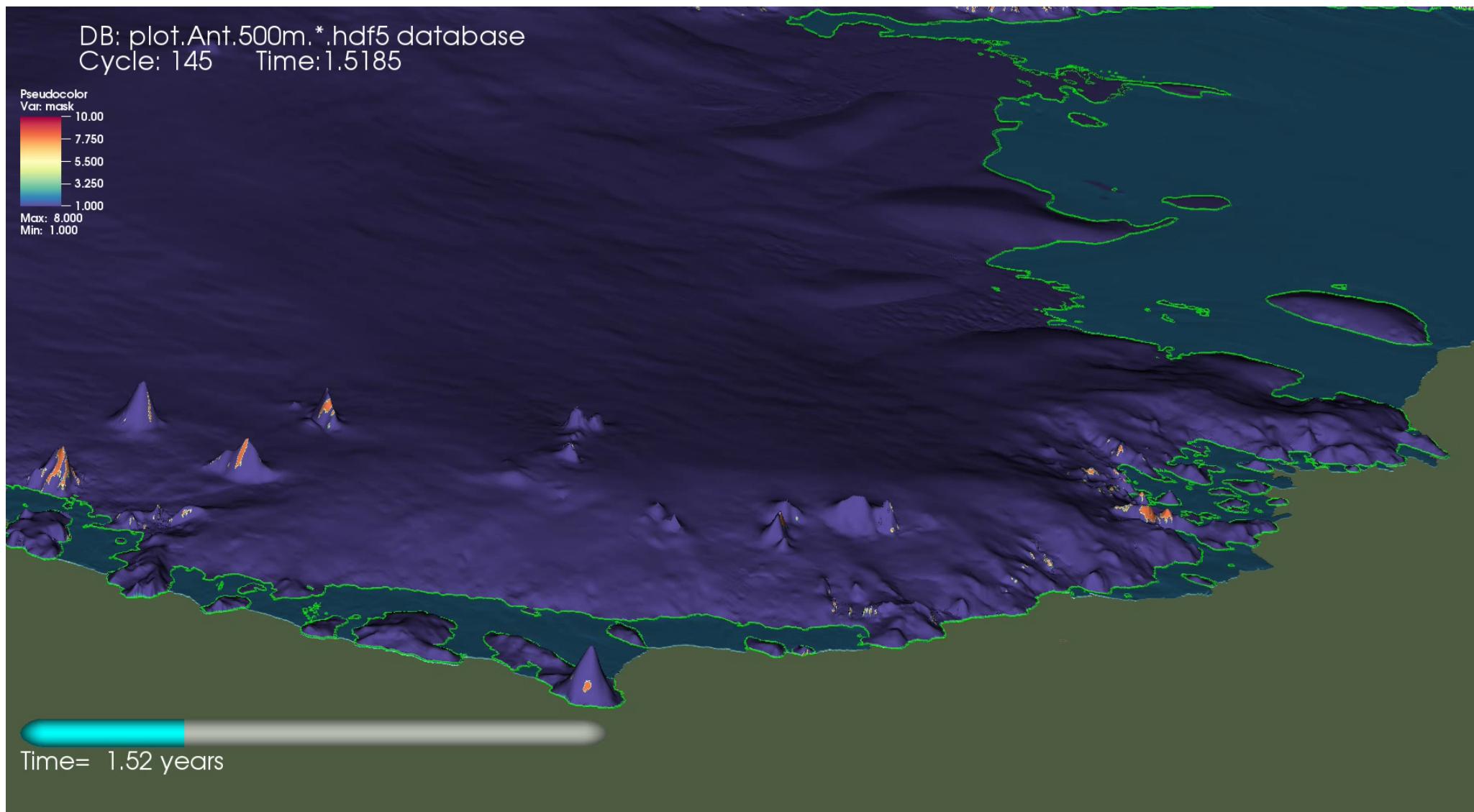
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